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Abstract
Dr. Ellis Miner, former science manager of Cassini, and assistant project scientist on Voyager, reviews Voyager's findings at Saturn, and what we are looking forward to learning with Cassini.

Coordinator I would like to inform all participants today's call is being recorded. If you have any objections, you may disconnect at this time. Ms. Sohus, you may begin.

Anita Good morning, everybody. I'd like to introduce Dr. Ellis Miner, former science manager of Cassini, and assistant project scientist on Voyager. Ellis is dear to all of us and has been involved in many, many, many of our missions before Voyager, even.

Dr. Miner You're saying I'm old.

Anita No. That applies to many of us. You are experienced. I asked Ellis if he could give us some reflections and also some information about what improvements we'll see with Cassini that Voyager had questions about, raised questions about, that maybe Cassini will be able to provide more information, so this is really freeform. Feel free to ask questions at any time.

Ellis, take it away.

Dr. Miner Fine. A lot of these things you can find on the Cassini Web site [http://saturn.jpl.nasa.gov], but perhaps, some of them are not there. In particular, I wanted to talk a little bit about what the situation was following the two Voyagers' flybys of Saturn back in the 1980 to 1981 time period. At that time, I was serving as the Assistant Project Scientist for the Voyager mission and so I had some intimate relationships with what was going on at that time and had an opportunity to talk about it to the press and others on a number of occasions.

At the time we flew by, there were a number of things that we didn't know about Saturn. Obviously, we had never sent a spacecraft there, other than the Pioneer spacecraft-- Pioneer 11 was diverted after having gone by Jupiter and sort of flew over the top of the Sun and on over to Saturn on the opposite side of the Solar System at that time [September 1979] and was able to get some good information.

The primary reason that NASA wanted to push for Pioneer to go there first was that we were concerned about the environment of the rings; and we knew that Voyager 2 and 1, both of them had to cross through the ring plane. Voyager 1, in fact, crossed through the ring plane twice as it flew by Saturn. We wanted to, number one, make sure that the spacecraft would survive crossing through the ring plane; and number two, that the charged particle environment wasn't as severe as we had seen at Jupiter and hence, perhaps of danger to the spacecraft themselves.

Now, it turned out that it was a really benign environment, as far as the charged particles were concerned. Pioneer actually survived two passes through the ring plane near the present location of the G Ring and, in fact, detected that G Ring, not because it saw it in any of the images that it took; but because it detected an absence of magnetospheric charged particles during that time period and said, "That must be due to a ring," and, indeed, it was.

That ring was first photographed by Voyager 1, as Voyager 1 flew by Saturn. Of course, one of the primary targets in the Saturn environment for Voyager 1 was Titan, and so we actually timed the encounter, such that we could have a very close flyby of Titan. What that forced us to do, because Titan's ring was relatively open at that time, it forced us after we flew by Titan, to fly south of Saturn and Saturn's gravity kicked Voyager 1 into a trajectory that took it well northward of the plane of any of the other planet orbits and so, Saturn was the last of the planetary encounters for Voyager 1.

After having had a very successful encounter with Titan on Voyager 1, one of the things that we had to decide was is it possible to get enough data from what we saw with Voyager 1, so that we didn't have to target Voyager 2 for another close flyby of Titan. While there were a lot of things that we didn't find out about Titan from Voyager 1, we did find out enough, that we were given permission to target Voyager 2 to go on to Uranus and Neptune, so it was really the success of Voyager 1 that allowed Voyager 2 to go onto the next two planets.

Just to talk a little bit about some of the things we found, I'm going to divide these discussions into about five general areas, and these five general areas are one, the atmosphere and interior of Saturn itself. The second area that I'll talk a little about is the ring system. The third area is the magnetosphere of Saturn and some of the things we found out about that and what we plan to find out from Cassini. The fourth is the other icy satellites and the fifth is Titan itself, and so with that as an outline, let's go through these a little bit.

Saturn's Atmosphere and Interior

Regarding the atmosphere, one of the things we wanted to find out is what the composition and the primary composition of that atmosphere was. We hoped that Saturn and Jupiter would be more or less the same hydrogen and helium abundance that we knew existed in the Sun from our studies for the Sun. That would have indicated that, perhaps, Saturn and Jupiter were both bodies that had been altered very little since the time of their formation some 4.5 billion years ago, and that turned out not to be the case. In fact, when we first went by Saturn and did a measurement of the helium abundance there, using data from both an infrared spectrum, or a series of infrared spectrums, and from the data obtained by the radio science experiment as the radio beam was transmitted through that atmosphere and received at Earth, was that the helium abundance was such that, we only had something like 4% of the total atmosphere composed of helium and the other 96% basically being hydrogen. That, of course, meant that Saturn was very poor in helium.

One of the things that we proposed to explain that was that maybe in the interior of Saturn, there is, like we proposed there was on Jupiter, a metallic, liquid hydrogen layer that was deep enough and high pressure enough, that probably the helium would have been liquid, as well, and helium, having greater density, would be sinking through toward the interior, toward the center. Perhaps, that sinking process would account for the reduced amount of helium in the atmosphere, and also perhaps, give us an explanation for why Saturn seemed to be giving off about 82% more energy than it received from the Sun.

Now, when Galileo reached Jupiter, it sent a probe into the atmosphere that actually measured the hydrogen and the helium as it was traversing the upper layers of the atmosphere. The consequence of that was that Galileo discovered that Voyager had made a miss-estimate of the amount of helium in the atmosphere of Jupiter; that we'd actually underestimated the amount of helium.

The infrared team went back and looked at their data after this and said, "If we basically ignore the radio science data, our data came out with a number that is fairly close to the number measured by the Galileo probe for Jupiter." So, what they did was a recalculation again, ignoring the radio science data for Saturn and discovered that, lo and behold, instead of 4% helium in the atmosphere, the number was 14% with an uncertainty of 3%.

That was one of the things that meant that Saturn wasn't nearly as poor in helium as we originally thought. It was much closer to the sun and maybe, at least the chemical composition of that atmosphere has not been altered as much as we thought through the processes that have occurred since its formation. That's one of the things we want to check again with Cassini and see if we can get a much better estimate and a consistent estimate from both the radio science and the infrared instruments onboard Cassini, as to what the real helium abundance there is. It has a fair amount of import, as far as our estimates of how much we'll learn about the formation processes of the Solar System.

M Just one quick question. Was that mass abundance?

Dr. Miner That was the mole fraction at 14%. The mass abundance is actually 22% helium; 22% helium, plus or minus 4% for the mass ratio, and 14%, plus or minus 3% for the mole fraction, the mole fraction being simply the ratio of the number of hydrogen molecules to the number of helium molecules.

Just a couple of other things. I already mentioned the excess thermal energy from Saturn. It doesn't give off more additional heat than does Jupiter because Jupiter, being closer to the Sun, has more energy coming in from the Sun. And so although it has a fair amount of energy also coming from its interior, the ratio of the heat coming from the interior to that being received by the Sun is higher for Saturn than it is for Jupiter.

We know there is something in the wind patterns at Saturn that we had not noticed in anything we had been able to measure from Earth; and that is that the wind patterns in the atmosphere are, like at Jupiter, organized at constant latitudes. You can pick a latitude and measure the wind speed for that entire latitude around the globe. We found that there was sort of a north/south symmetry in the wind patterns seen by Voyagers 1 and 2 at Saturn.

In fact, one of our scientists, Andy Ingersoll [professor at California Institute of Technology], who is also on the Cassini project, indicated that it was almost as if Saturn were rotating in individual cylinders; and that those cylinders were at constant distance from the rotation axis of Saturn and represented the way the interior of Saturn was moving by the cloud patterns or the wind patterns that we saw at the surface clouds. I think that's pretty well been discarded since then, but it is curious that this north/south symmetry is so strong in the case of Saturn. It is not in the case of Jupiter, for example.

Temperatures in the stratosphere were measured. The temperature at a pressure that's about a tenth of Earth's atmospheric sea level pressure reaches a minimum of about 80 Kelvin; and they go upward from that about 140 Kelvin at a thousandth of a bar, a thousandth of Earth's atmospheric pressure. Of course, they also increase downward monotonically from that 80K level, and it's about 125 at the cloud tops and continues to get warmer and warmer until it gets into the thousands of degrees in the interior of Saturn.

We saw polar aurora in the ultraviolet associated with charged particles from the solar wind spiraling down magnetic field lines and striking neutral atoms in the upper atmosphere of Saturn. Those auroral emissions were not as strong as at Jupiter, but nevertheless, they were quite visible there.

We saw something that we still haven't adequately explained, and that was some electrostatic discharge-type things that we're seeing with our planetary radio astronomy experiment. They had a basic periodicity to them of about ten hours and ten minutes. Originally, it was thought, since the rotation of the interior of the planet is a little longer than that, about ten hours and 39 minutes, that this might have been something happening within the rings, maybe charged particles within the rings touching each other and discharging.

But I think we now believe that it's probably associated with either lightning or other such electrical discharges in the atmosphere near the equator of Saturn, where the winds at the equator of Saturn are strong enough, that the equatorial atmosphere actually circles the planet in less time than the interior of the planet. That's one thing we want to look at again and see if we can see exactly what the source of those things would be.

Now, as far as the atmosphere of Saturn is concerned, the things that we're looking for in the Cassini objectives, we want, of course, to get the compositional abundances of the main gases, but also some of the minor constituents that we are quite sure exist there, both from Voyager and from theoretical considerations.

We want to check, again, the wind speeds and directions. The zones look a little bit different on Saturn now, than they did when Voyager 1 and 2 flew by. We want to see if the wind speeds are organized the same way as they were then by latitude, or if they have changed in the meantime. Change would, of course, imply something about the nature of those winds that would be different.

The internal structure and dynamics of the planet, we want to look at the clouds that are forming there. We want to look at the mass. You can not only measure the mass of the planet, but how that mass is distributed in the interior and from that, distribution of the mass and the interior. You can do that from measuring the pull on the spacecraft as the spacecraft orbits the planet, particularly when it's close to the planet.

When we measured Saturn, we, of course, flew by twice, once with Voyager 1 and once with Voyager 2, during which time we transmitted the radio beams through the atmosphere and the ionosphere of Saturn. And at that time because seen from the Earth, Saturn seems to have a full phase, that is, it's fully illuminated as seen from the Earth to within something like three degrees or something, a little more than that, maybe, six degrees. We were not able to measure the ionosphere more than right at sunset and right at sunrise. We'll have a little more opportunity with time to look at those ionospheric variations on Saturn that could tell us a little bit about it.

Scenarios for the formation and the evolution of the planet, some of the sources and the characteristics of lightning and radio emissions, we did not see any lightning on Saturn. One of the things we hadn't anticipated, when we tried to look at the dark side of Saturn with Voyagers 1 and 2, was that the rings were such a source of light, that the dark side of the planet was lit up with ring light; and therefore, the atmosphere was too bright for us to really do the long exposures we did at Jupiter and pick up lightning bolts that might be striking there.

We'll have a chance, both to look at them in the camera pictures, that is in light that is in the visible realm or in ultraviolet light; but we'll also be close enough to the planet frequently enough, that we should be able to see the whistlers and other radio signals that come from lightning that is generated either on the illuminated side or the dark side of Saturn. So that's one of the things that we would like because that would tell us a little bit about the dynamics of the atmosphere, if there's actually lightning being created there.

That covers the atmospheric objectives. The main instruments that contribute to those studies are our radio science experiment and some of our remote sensing instruments, like the composite infrared spectrometer, the imaging system, the ultraviolet imaging spectrograph, and the visible and infrared mapping spectrometer, as well as, of course, the radio and plasma wave science that will be looking for the radio waves coming from the atmosphere.

The Rings

Moving onto the rings, when we looked at Saturn from Earth, we noticed that it was divided into main rings, A and B Rings, with the Cassini division in between and we had seen something of the C Ring and some individuals had claimed to have even seen a D ring inside of the C Ring. Pioneer had discovered this F Ring and its images and saw evidence for a G Ring. And of course, we knew that from the times of ring plane crossings, that there was a tenuous ring that extended out well beyond the visible rings, called the E Ring, so all of those we knew about.

We attempted to photograph and characterize each of these with Voyager. We did discover a D Ring inside of the C Ring, but it was far too faint to have ever been seen from Earth; and so apparently, we should attribute the actual discovery of the D Ring to the Voyager spacecraft. We did see the G Ring in images from Voyager, again, between the orbits of Epimetheus and Janus and the orbit of Mimas. We looked at the F Ring carefully. There were places where it had the appearance of kinks or braids, almost, in the F Ring, apparently due to complex interaction between the F Ring particles and the shepherding satellites, Prometheus and Pandora.

I'll talk more about Prometheus and Pandora later, but we now have evidence from theoretical considerations and then by looking back at the Voyager images, that the F Ring has kinks that are regularly spaced around the F ring that correspond to the distance in the F Ring between successive encounters of Prometheus and Pandora. Of course, the outer satellite moves a little bit slower than the inner satellite, so every once in a while, one laps the other, and in that lap time, the F Ring will have gone around a number of times. The areas where those encounters occur apparently are affected in some strange way that causes the F Ring to develop little concentrations of matter or kinks or whatever it is. We'd like to investigate that a little more closely with the Cassini spacecraft, see if we can determine that a little more carefully.

M Can I ask a general question about the rings? What is the material density inside the densest of the rings? How many objects per cubic meter or whatever figure of merit you have there?

Dr. Miner The spacing is tightest in the B Ring, where I would estimate that you probably have something on the order of a few percent of the total space filled with particles. They are relatively close there and flying a spacecraft through that ring would be well nigh impossible. When you get into the C ring, the particles are much farther apart. In the E Ring, the particles are probably separated by many hundreds of thousands of times, times the particle size. But the particle size, remember, is on the order of a micron and so that means, still, as you fly through the rings with a spacecraft, that you can have several hundred hits per second as the spacecraft moves through the ring plane at relative velocities of a few kilometers per second. That gives you an idea.

They are not so tightly spaced that it would be impossible to weave your way through them if you had a manned spacecraft that was trying to do so; but it would be rather hazardous for an unmanned spacecraft that can't see in advance where those particles are. And of course, we wouldn't be able to react in time from Earth, since there's a round trip light time that is so long, basically, 80 minutes one-way light time, that we would have difficulty navigating through the ring plane, especially anywhere near the A or B Rings. We're even concerned about it out in the E Ring when we're near the orbit of Enceladus, where we think most of the E Ring particles originate.

M I have a question regarding your maximum resolution, which was not answered by Dr. Cuzzi, actually, in the last telecon, just after the orbital insertion and before ring plane crossing again.

Jane: Could the speakers say who they are?

Carter It's Carter Emmart from the American Museum of Natural History.

Dr. Miner Our closest approach to the rings during the time we're trying to do the imaging of the rings, is something on the order of 10,000 kilometers above the rings. We don't get that close to it and so, with the resolution of the cameras, we will probably not resolve individual ring particles, even at that time, and that's the closest we get in the entire mission. Our resolution element is sort of on the order of a tenth of a kilometer or something of that sort, and we anticipate that the majority of the particles are between a few centimeters and a meter in size. There are larger and smaller ones, of course, as well.

Voyager discovered some elliptical rings in some of the gaps within the main ring system, particularly one within the Encke Division and another one within the Maxwell Division inside of the Cassini Division, if you want to call the Cassini Division as is a really a populated of a division. We'd like to see what the nature of those are. There are also some places where there appear to be discontinuous rings within those gaps. These gaps usually occur at places, where there is a strong satellite orbital resonance with one of the larger satellites or one of the nearby satellites. Those are things we want to investigate.

Of course, the markings in the rings, the radial divisions in the rings, are far more than we can explain with only gravitational effects of the moons that we are familiar with. So we want to find out whether there are other moons that are causing some of those markings that might be as yet undiscovered or potentially, are there some other mechanisms that are causing some of the divisions that we see within the rings or some of the radial markings, at least, that we see in the rings. That's one of the primary objectives.

We discovered that the outer edge of the B Ring is not circular; it's elliptical and the ellipse is centered, rather than being at one focus like you would expect Saturn being at one focus of the ellipse or like you would expect for most normal orbital things. We concluded that this has to be due to gravitational interaction with Mimas.

An upper limit of ten meters on the thickness of the rings, at several spots on the A Ring, is something that we discovered from Voyager. We don't know exactly what the thickness of the B Ring is, but it's got to be less than about 500 meters and maybe as little as 100 meters or less. The C Ring has an estimated thickness of about 50 meters. The E Ring itself, of course, is much broader. There are different types of interactions going out of those distances from the planet, and so the thickness of the E Ring, especially out around the orbit of Enceladus and just beyond is almost half the diameter of Saturn itself, and Saturn's diameter is 120,000 kilometers. You get the idea that it's a very thick ring out there.

A typical ring size … particle sizes range from micrometers in the E Ring to tens of meters or larger at certain places within the A and B Rings. There's probably a radially varying size distribution, too, which we haven't really characterized well with Voyager data, but hope to with Cassini data. Several of the rings have very sharp outer edges, where the populated region of the rings is well populated near those outer edges, but beyond them, basically empty. There are shepherding mechanisms that confine the ring material, and all of you are familiar with that already.

There is some indication of small compositional variations between the major rings, as well as within the C Ring. That may lend credence to a theory that the rings are formed from the breakup of individual moonlets that used to exist in the Saturn system that wandered within the so-called Roche Limit and therefore, were broken up by the gravity of Saturn and formed into the rings that we presently see. How much compositional variation there is, we don't know, but it may be mainly the minor constituents that are causing most of the compositional variation because we think the rings, at least the A and B Ring that we can see quite clearly enough to get a spectra of them, seem to have, as at least a major constituent, water ice.

The other thing I wanted to mention on the B Ring, that we will again investigate in more detail with Cassini, is these radial spokes that appear on occasion within the outer half of the B Ring at a distance where the B Ring orbital period is almost identical with the rotational period of the magnetic field, which is about 10 hours and 39 minutes, as I indicated before. Those spokes form over relatively short periods of time, sometimes extending for thousands of kilometers in a radial direction in the rings and very quickly, moving with the angular speed of the magnetic field and therefore, maintaining their more or less radial nature or sometimes, two or three obits around the planet before they disappear, which sort of means that somehow they're moving at the same speed, regardless of their distance from the planet, as the magnetic field.

The only way we think that could happen is that somehow, the particles in that ring are small enough, that they are being ionized by some process, probably photoelectric, sunlight, in other words, shining on those particles and partially ionizing them, enough that they are effectively frozen in the magnetic field, rather than moving with the orbiting ring particles that aren't charged underneath them. We want to look at that a little more.

As far as the Cassini ring objectives: the shape and the structure of the rings and their formative processes; the composition and the sizes of the rings particles; the relationship between the rings and the moons; the distribution of dust and meteoroids, we didn't have any experiments on Voyager that allowed us to measure the dust and the meteoroids in the vicinity of the spacecraft and we do now; and the interactions between the rings and Saturn's magnetosphere, its ionosphere, and its atmosphere. That's where we're headed with Saturn.

Ken This is Ken Phillips in Los Angeles with another ring question. What about the stability of the rings over time? Is there any effort on this mission to determine if they've, let's say, gone away for a period of time, maybe reformed by whatever process, the length of duration over which they are likely to remain stable and visible? Will you try to get at that?

Dr. Miner To the extent that we can in the length of this mission. We will, of course, be looking very carefully for differences in the radial distribution of particles between the Voyager encounters, where we saw basically the same thing with both Voyagers 1 and 2. That sets a lower limit on the amount of time it takes the rings to change. They were about, something like nine months apart. The time between the Voyager encounters and the Cassini orbit is a little closer to about 25 years and so, we'll get a little better idea of what the variations are over a 25-year period.

Of course, intermediate to that, between the beginning of our orbit around Saturn and the end of it, will be a period of almost four years; and so we should look and be able to see if there are any strong variations in the radial characteristics of the rings over a four-year period.

A combination of those things should enable us to tell a little more about the ages of the rings, how long it takes them to form, how quickly they change, what the nature of those changes are, and whether the rings have been around as long as the planet or not. Our present theories are that the ring material is depleted at a rate, which probably means the rings aren't more than a few hundred million years old, at least the present particles within the rings. Now, maybe the rings have always existed, but not with the same particles. They have to be replenished, by one means or another and that replenishment may come from the breakup of some of the inner moons. I don't know if that answers your question or not, but yes, we will be looking specifically for time variations in the rings.

Anita Ellis, is there something that you're just dying to know about Saturn?

Dr. Miner Something I, personally, am dying to know about Saturn?

Anita Yes, what are you looking forward to the most about learning about Saturn or Titan or anything?

Dr. Miner Probably, Titan. I would love to know just what the nature of Titan's surface is and whether or not it is a place that's going to warrant further investigation afterwards. My gut feeling is that, "Yes, it will be."

Anita Are you going to know very much, from the radar or anything, before January?

Dr. Miner Not a whole lot. We will hopefully be able to get one or two swaths across the surface and that may tell us whether there's a liquid surface there or not, if we happen to go across liquid areas. If we don't, then we won't learn about those. I'm not convinced that we will learn everything we can about the surface of Titan, even after the Huygens' entry has occurred. It depends on how much variability there is on the surface. We do know that there's one bright area. We've seen that in the infrared pictures from Earth, but whether that's a continent, whether it's just a highly reflective portion of the surface, whether the less reflective portions of the surface are liquid or solid, we really don't know at this point. I would love to find that out.

Carter A question from Carter from the American Museum. How often, out of the 74 encounters with Titan, are you actually doing a radar experiment?

Dr. Miner About a third of the time is all. There are only 44 flybys of Titan, unfortunately. There are 74 orbits of the planet, and so about, maybe 12, 13, or 14 of the passes, I think, is what we're presently planning will be dedicated to radar measurements. We will get measurements from a greater distance, using passive microwave radiation in the radar system to try to map the surface, but the high resolution mapping, probably just those 10 to 15 passes.

Anita Still more than you got with Voyager.

Dr. Miner Yes, far more than we got with Voyager. I'm going to skip over the next couple of ones fairly quickly, so we can concentrate, maybe, for the last 10 to 15 minutes on Titan.

Magnetosphere

The magnetosphere, there are a couple of things we found out. We had only two passes through the magnetosphere, and they were not at ideal orientations because they were controlled by the targets that we had for each of the two spacecraft, in the case of Voyager 1, the flyby of Titan and Voyager 2, the continuation onto Uranus. We did measure the internal rotation of Saturn from pulsed radiation that is sent out by the planet for the periodicity of 10 hours, 39.4 minutes. We assume that's the rotation of Saturn's interior at present, but we don't know where the source region for the radio waves is.

One of the things we're going to look for in our Cassini observations is, very carefully, where that radiation may be coming from. There is some thought that it may be in the northern hemisphere because we saw it less strongly in the southern hemisphere than we did in the northern hemisphere, but we don't know that for sure.

The other thing about the magnetosphere that is curious is Saturn is the only planet with a measured magnetic field, whose magnetic tilt is less than one degree from its rotation axis. If it's perfectly aligned, we aren't quite sure how the magnetic field can be generated. Dipolar magnetic field generation theory at present says that there has to be a tilt in order to keep the magnetic field going. And so the fact that there's not, at least that we can measure as yet in Saturn, gives us reason either to question whether our theories about magnetic dynamos is correct, or whether there are other mechanisms for generating magnetic fields than the ones that we have estimated up to this point. That measurement of the actual tilt of the magnetic field relative to the rotation axis is a prime thing that we're going to be looking for on Cassini.

Icy Satellites

As far as the satellites are concerned, Voyager actually discovered four new satellites, but also, made the first measurements of most of the other six to, let's see, at that time that we flew by, there were a total of 18 that we found, including Pan that was discovered in the Encke Gap; so the other 14, we made measurements of all of them, although some of them were not disk resolved measurements. At least we got some idea of their brightness and hence, of their approximate size, if we made some assumptions about their surface reflectivity.

We were also able to make some estimates of the mass of these objects from the deflection of the spacecraft and the radio signals that were being taken during those deflections. We won't be able to do that quite as easily with Cassini because we don't keep the antenna pointed at Earth during the times that we're flying by these objects, generally, and that's because in order to take data with Cassini, we have to point the whole spacecraft. All the instruments are body fixed, so that when we point the instruments, we can't keep the antenna pointed at Earth.

Anita What resulted in the decision to make them body fixed?

Dr. Miner That was an interesting series of things that probably most of us regret at this point, but I think it was still necessary. We had to get the mass of the spacecraft down to a point, where it could be launched on a Titan Centaur. If we had kept all of the scan platforms and other appendages on there, the mass of the spacecraft would have been enough larger, that we would not have been able to actually launch it with a Titan Centaur rocket, and so we did have to reduce the mass somehow.

There may have been other ways of doing it, but as far as the other reason, there was also a desire to keep it within certain costs. And although we did, by making the instruments body fixed, reduce the costs of building the spacecraft, we increased enormously the cost of operating the spacecraft after launch. The consequence of that is that the mission as a whole will end up being more expensive than it would have been if we had had a steerable scan platform, unfortunately. It's a lesson, I guess, we learn after the fact, but I doubt very much that we'll ever try and launch another outer planet spacecraft without having a scan platform attached.

The two most interesting satellites are, from my point of view, outside of Titan, are Enceladus and Iapetus, Enceladus because it has a very fresh, bright surface. Its albedo is essentially unity, meaning that it reflects basically all the light that strikes it, and that means it's got a relatively fresh surface. We've also seen evidence that some of the crater events of the past have been wiped out, sort of like the surface is partly melted.

The fact that it's closest to the densest part of the E Ring gives us reason to believe that there may be some sort of a particle source on Enceladus. Some have even speculated that there might be ice volcanoes on Enceladus that are spewing ice particles in space around Enceladus that are feeding the E Ring, keeping it from disappearing altogether.

Iapetus, the other one that was discovered by Cassini [the astronomer], was seen only on one side of the planet by Cassini [the astronomer], who correctly deduced that this must be a satellite that keeps its same face toward the planet all the time; and that the forward face, the face that you would see on the left side of the planet if you were looking to the sky, was darker than the receding side on the right side. Of course, he would have seen it the other way around because he had an inverting telescope, but just looking into the sky on the western side of the sky, you would be able to see Iapetus much more clearly than you could on the eastern side.

That dark material on the front face of Iapetus, as it moves around Saturn, is still an enigma. We don't know where it comes from. I heard a talk just about a week and a half ago on that topic, and the situation is not much clearer now than it was back in the days of Voyager, more than 20 years ago. We still do not know what the material is on that front face of Iapetus and that's one of the things we want to determine, so we do have one close flyby of Iapetus, three close flybys of Enceladus.

Titan

Moving now onto Titan: we made the first measurements of the surface dimensions of Titan with Voyager. We found out that its atmosphere was quite thick. In fact, the surface pressure, measured again by the radio science experiment, is about 60% greater at the surface of Titan than Earth's at the surface of Earth, and that's the only satellite in the Solar System where we have an atmosphere anywhere near that thick.

The temperature at the surface was discovered to be somewhere in the neighborhood of 95 Kelvin, which means that there wasn't a greenhouse effect, at least, not as strong a greenhouse effect as some had speculated, acting on Titan. There was, indeed, a thick haze covering the entire surface of Titan to the point where all of the carefully planned images we took with Voyager returned basically nothing of interest about the surface itself.

We've gone back and processed some of those images and we can begin to pick out something that is a semblance of surface detail, but certainly not as detailed as some of the data that we've gotten in the infrared from Earth, both from the Hubble Space Telescope and from adaptive optics with ground based telescopes. We do know a little more about the surface of Titan than we did even after having reprocessed some of the images from Voyager, but not enough to really tell us what that surface is like.

The atmospheric composition was discovered to be mainly nitrogen with some methane and we thought, at that time, probably argon. I think other studies since that time have concluded that the amount of argon in that atmosphere is probably not very large, so it may not be a major constituent like at one time it was thought to be.

We found trace amounts of a whole bunch of other things, like carbon monoxide, ethane, propane, acetylene, ethylene, methyl acetylene, diacetylene, and hydrogen cyanide. The hydrogen cyanide was particularly interesting because that was the first evidence we had that there was nitrogen in the atmosphere. Then, cyanoacetylene, also a nitrogen compound. Cyanogen, a nitrogen compound, and small amounts of carbon dioxide, and a little bit of oxygen, but probably no free oxygen in the atmosphere.

There are strong implications that Titan's surface may be covered with a liquid ethane ocean. We couldn't figure out how else methane could be maintained in the quantities that was being maintained in the atmosphere and the temperatures are such, and the material that we know about in the atmosphere is such, that the main constituent of the surface probably is ethane with maybe a 25% mixture of liquid methane and possibly, a little bit of liquid nitrogen in it, as well; although we don't know that for sure.

We detected this main haze layer extending up to just over 200 kilometers above Titan's surface. Remember, Earth's atmosphere is essentially non-existent, once you get above about 100 kilometers. Titan's atmosphere still has a detectible amount of material at nearly 1,000 kilometers. In fact, when Cassini flies by, we'll be flying by through the outer reaches of the atmosphere of Titan and actually making measurements of the composition of that upper atmosphere with the Ion and Neutral Mass Spectrometer.

We have to be careful before we get too close to Titan to ascertain what the density of the atmosphere is in detail because it, of course, will create some drag on the spacecraft as we fly by Titan. We want to make sure that drag isn't enough that we lose our ability to control the attitude of the spacecraft. Otherwise, our pointing at the surface and other things will not be as we intend it to be.

If we find that the atmosphere is less dense than our present worst case estimate, we will, later in the mission, hopefully be able to fly a little closer to Titan and, perhaps, sense the atmosphere with the Ion and Neutral Mass Spectrometer a little better.

Those are the main things, I guess, about Titan. Cassini's objectives for Titan include a number of things: abundance of the gases; learning how Titan formed and evolved; what the trace gases are; complex organic molecules; some of the chemical energy sources; what winds there are; the global temperatures; the cloud properties; a search for lightning; the nature of the surface, of course, whether it's liquid or solid; again, through our many flybys, hopefully being able to determine, on the basis of its effect on the spacecraft orbit, the internal structure of Titan. We think the majority of Titan is made of water ice, underneath whatever the surface layers are and underneath the hazy atmosphere. And then we think that the upper atmosphere and the ionosphere of Titan may actually be sources of material in the magnetosphere of Saturn. So we're going to try and look at that as well and try to see, also, whether Titan has its own intrinsic magnetic field, which we don't anticipate will be the case, but it may be.

Q&A

That covers Titan. We have a few minutes left for questions, if there are some particular questions that you would like to ask.

Steve I have one. This is Steve in Rochester, New York. Could you review for us the very, very inception of the Cassini project? Was it in the works at the time Voyager was happening or did the idea emerge later?

Dr. Miner There were two investigators on the Voyager mission who were particularly interested in learning what Titan was like, as Voyager 1 flew by. Immediately after Voyager 1 flew by in 1980, these two investigators got talking about the need to send another spacecraft back to the Saturn system; and one was in the European Space Agency, the other was in NASA, Toby Owen [University of Hawaii] and Daniel Gautier. They are both principle parties in the Cassini mission and are really responsible for the idea, the inception of the idea, of the Cassini-Huygens mission.

Shortly after that proposal, the European Space Agency proposed to build an instrument, the Huygens Probe and did so, I think, quite effectively. Of course, once that was built, NASA proposed to build the orbiter to carry it there and to relay the data from it and a few other things of that nature, as well as to include a rather extensive suite of instruments to put on the orbiter to do measurements from orbit around Saturn.

Steve So Huygens came first?

Dr. Miner The Huygens Probe was the first to be proposed, yes.

Anita What year was that, do you remember?

Dr. Miner It was 1980, even before Voyager 2 had arrived.

Anita Ellis, this is incredible. I'm sure you're doing this totally off the top of your head with no notes.

Dr. Miner Right. I have a few things in front of me.

Ken Is there time for one last question?

Anita We have the line actually, I think, until 12:30. It's more honoring Ellis' time.

Dr. Miner We can go on. I don't have any other commitment until after 12:30, so if any of you have questions that you'd like to continue to ask, we can go on; but if you want to cut it off, we can do that as well.

Ken This is Ken, again, in the Los Angeles Science Center. I just had one quick question about the CRAF [comet rendezvous/asteroid flyby] mission, I guess, that was cancelled. My understanding was that there was at one time, a generic spacecraft bus onto which different science packages could be placed. Is that correct, or were there always separately tracked missions, only one of which survived, that being Cassini? What's the story on that?

Dr. Miner You're absolutely correct. There was something called the Mariner Mark II spacecraft that was designed to handle both the CRAF, comet rendezvous asteroid flyby mission, and the Cassini mission. The structures of the two were to be identical. Some of the instruments would be different. We had, of course, different principle investigators and different team leaders for the different investigations on the two missions. But they were both to have a turntable for fields and particles instruments, a scan platform for the remote sensing instruments. Cassini was to have a radar system, which CRAF did not have, but both of them had a threefrequency radio science system. In fact, the two missions were run as a single project at JPL up until the time that CRAF was cancelled.

Anita Steve, do you have any more of those nine-year old questions?

Steve Actually, there was one I was wondering about a couple weeks ago. Maybe Dr. Miner knows about them. What will happen around the time of solar conjunction, which is, I understand it is July 8?

Anita That's a nine-year old question?

Steve No. The nine-year old will ask if we can see Saturn through a telescope, while we're watching the orbit insertion and we'll have to explain that.

Dr. Miner Yes, that's going to be a little difficult. One of the reasons that the encounter is on the 1st of July, instead of on the 5th or 6th of July, is to avoid having the Saturn orbit insertion be right on top of that solar conjunction. We could have actually gotten an easier passage of Phoebe on the way into Saturn if we had delayed the encounter a few days. But that was as late as we dared delay it, because we wanted to make sure that we had some tracking data from the spacecraft after its orbit insertion, to make sure that it was inserted into orbit around Saturn before we potentially lost contact with it for a few days around solar conjunction.

Solar conjunction is a difficult time. We have now concluded that if we plan carefully, we can probably do semi-routine activities on the spacecraft through the solar conjunction period. But that we, in general, will not try to transmit data back to the Earth during the solar conjunction period, which, in general, we've estimated to be effectively a week in length. There will be about a week of time there after the orbit insertion and the initial tracking data, where we will be unable to communicate freely with Cassini, and thereafter, of course, we'll be able to communicate. Once a year, we have that same problem again, but we can control the timing of the others a little more easily than we can control the orbit insertion time.

Steve Will you be able to see it at all? Are there any solar physics ideas using the radio signal during this time?

Dr. Miner We had talked about the possibility of using Ka-Band in the radio science system to transmit a signal back to the Earth. But during the SOI time period, of course, we have to point the motors, the burn engines, in the direction of motion of the spacecraft, in order to most effectively slow it down. That means that our communication with the spacecraft at that time, if there is any, will have to be by means of the low-gain antennas. It's marginal whether or not we can actually receive clear signals from the low-gain antenna[at that time].

We think that if we don't try to transmit any telemetry at that time, but just transmit a carrier signal, that we ought to be able, over the low-gain antenna, to keep constant communication with the spacecraft, to see whether its velocity is changing the way we would predict it would change during an orbit insertion burn. We should be able to tell whether the burn is working okay. But we will have to wait until after the burn is over to transmit the details of the burn data back to Earth and see whether or not there's some possibility of things not having happened exactly the way we thought they should.

Steve I was thinking that a few days later, during solar conjunction, will you be able to see any signal from the spacecraft, at all, through that time?

Dr. Miner I think there will be an attempt to transmit some data during that time. I don't know precisely what the plans are there, but hopefully, they will be testing the limitations of the system as far as transmitting during those times. In the past, we've generally used S-Band, which is a little more susceptible to solar conjunction losses than the X-Band that we're using for data on this spacecraft. We may be able, in fact, to get within a day or so of the center of the solar conjunction period, rather than having to wait several days on either side; but I don't know the details of that planning at present. I do know that they are not planning to transmit critical data back during the solar conjunction period.

Carter A question from Carter from the American again. Looking at the trajectory of Cassini post burn on its first orbit out, it looks as though at the …, that there's a delta V that occurs. I was just wondering is there a second engine firing out there, helping to put it into a proper orbit.

Dr. Miner Yes, we do another trajectory correction maneuver. It's called the periapsis raise maneuver. It has two purposes, one of which is because of the ring hazards and because of the radiation potential in close to the planet, we do not want the spacecraft to go that close to Saturn ever again, at least until we're late enough in the mission that a possible failure won't affect the mission outcome. We raised the periapsis at that time, the pericrone, if you will, at that time, such that our closest approach to Saturn from that point on is always out around three Saturn radii or larger. Whereas, of course, in the orbit insertion, we're well within two Saturn radii.

We also at that time target for an impact with Titan. That's so that when we get ready to release the Huygens Probe, we'll already be on a coast trajectory that will impact the landing spot on Titan. Of course, after we release the Probe, then we have to do another maneuver in order to make sure that the orbiter spacecraft doesn't follow the probe into Titan.

Anita Anybody else have questions for Ellis while you have him?

Steve I have another nine-year old one. I wonder how many children think we live inside the Earth, but children always ask, "What's inside the planets?" There's a book that comes out every few years called *The New Solar System;* and the latest edition has these little pie charts showing layers in the interiors for the giant planets. Looking back here at my notes, it seems like there might still be a fair amount of uncertainty about how we should draw these sketches of the interior of Saturn. Am I right about that?

Dr. Miner I think you're right. Bill Hubbard at the University of Arizona is probably one of the foremost experts on it and I think he, in fact, was one of the authors of *The New Solar System* article on the interior of the planets. I don't have the newest version here. I've got that newest version at home.

Steve I've got it right here and yes, he is the author.

Dr. Miner The more data we have on the distribution of mass in the interior, the more accurate are the models that we can put together of the interior. Right now we believe, of course, that the upper atmosphere is mainly hydrogen and helium down to the cloud tops; and that beneath those clouds, which are probably ammonia ice, we go through successive cloud layers, beneath which the abundance of the materials out of which the clouds are made is a step function.

Eventually, once we get down below the water ice cloud, we should find larger and larger percentages of water and methane and ammonia that continue on down until the temperatures and pressures get high enough that eventually, the hydrogen and helium, again the main constituents, are pressurized into liquid hydrogen and helium. And even deeper in the interior, probably, in the case of Saturn, about two-thirds of the way to the center as I recall of this diagram – I'm just reconstructing it from memory – we have a transition zone where the pressure on the hydrogen, I should say, the pressure from the overlying material is great enough, that the hydrogen is actually converted into a metallic hydrogen layer.

It's probably in that metallic hydrogen layer, which is the first of the layers we've reached that is really highly conductive electrically, that we think the magnetic field of Saturn and of course, of Jupiter, originate.

Then, somewhere down near the center, there is an Earth-sized core composed of heavier materials, probably still in a molten state, but very likely most of the heavier ices and rocks and metals are in a molten state in a mixed type of situation down near that Earth- size center, at least that's our present theory.

Again, any time we get new data, we have to revise those models according to the data that we have. For example, the business about the abundance of helium in the upper atmosphere that was just revised a couple of years ago – about five years ago now – certainly has implications, as far as what's happening in the interior, as Saturn is concerned.

Alan This is Alan up at the University of Maine. Along those lines, here's a nine-year old question for you. What does metallic hydrogen look like?

Dr. Miner I have asked that question myself. I suspect that it's probably still a relatively clear liquid, but it would have some of the same types of characteristics as mercury does here on Earth, mercury, of course, being a conducting metallic liquid, obviously, not nearly the density of that material because hydrogen has a very low density, much less than that of water; whereas mercury is much heavier than water.

Alan You wouldn't characterize it as a solid, then.

Dr. Miner I would not characterize it as a solid. It's definitely liquid.

Alan From my curiosity, you talked about the lack of inclination of the magnetic axis of the planet. You also mentioned earlier the extraordinary symmetry in the structure of the weather patterns, as in stacked cylinders, all the stacked cylinder imagery as you go north and south from the equator. Have there been attempts to … the correlation that might mate those two observations?

Dr. Miner We presume that over time the amount of solar energy incident on the atmosphere and the amount coming from the interior are probably relatively evenly distributed around the equator. That is there's no reason why you would have, over a year on Saturn, would have more over energy in the northern hemisphere than in the southern hemisphere. Now why the winds tend to have varying wind speeds, I still don't know, either for Saturn or for Jupiter.

We do see in the evidences from laboratory experiments that have tried to simulate what's going on in the atmospheres the kind of thing that appeared in this series of photographs that were released about a week ago, where you see two of the circular storms on Saturn coalescing [http://photojournal.jpl.nasa.gov/catalog/PIA05386]. We've seen that in our laboratory experiments and some of them do get as large, relative to the size of the planet, as Jupiter's Great Red Spot. To understand fully why that symmetry exists, I think would require a lot more information than we presently have about the planet. I would be interested to see if we can get some of that out of Cassini.

Anita Okay, any other questions for Ellis? Any questions for me or Jane?

Jane Questions for Cassini Outreach? A lot of the information that Ellis talked about, about instruments and so forth, you can find a lot more detail on our Web site.

Dr. Miner Absolutely.

Jane That's just another plug for the Cassini-Huygens Web site. There's a section on the spacecraft, on the science objectives, and all of us are busily writing new sections and updating a lot of the science pages. Shannon is doing a lot of work on the science pages. Every time you go to the Web site, you'll find new and amazing things.

Anita Which is, the Web site is?

Jane And that Web site is www.saturn.jpl.nasa.gov.

Anita Is Eric on the line?

Eric Yes, I am.

Anita I wanted to talk to you about server space. Have you got 30 or 40 megabytes you could host something from Steve Fentress from Strasenburg Planetarium? They have a panorama they would like to share.

Eric How many megabytes?

Anita Steve, are you there?

Steve Yes, I'm here.

Anita Thirty or 40, you said?

Steve Something like that. It's nine panels, plus maybe a little text file to go with it. It's something that has really worked for us, so if there are others who might find it useful, we'd be glad to put it up there. We are not technically equipped to host it ourselves. Now, Anita, you mentioned the possibility of putting it on one of your DVD distributions, which may also be an economical way to do it, but 35 to 40 is probably—

Eric That's not a problem for us. We have plenty of disk space, so yes. We'd be happy to do that.

Anita Let's do a meeting offline about the best way to get that here, an ftp site or send this out on disk or whatever.

Steve I could mail you a disk and you can handle it as you wish from there.

Anita Great.

Eric That sounds the most efficient way to do it. Good.

Dr. Miner Maybe I can ask a question for Jane. On the day of orbit insertion, I will actually be in Yellowstone Park. I would love to be able, through public television or a Website – I'll probably have my computer along – be able to see some information on what's happening with Cassini. What is planned in the way of that? Maybe you've already talked about that with the individuals on the telecon here, but I haven't heard it.

Jane We touched a little bit on some of the scheduling at the last telecon. Shannon, are you on the phone? I have a schedule here that has – I have Veronica's, Veronica is our media relations person – a timeline of when things are going to happen; but as far as the actual, let's say, Wednesday, June 30th, I have an hour-by-hour breakdown.

Dr. Miner I'll have to get that from you. I'll talk with you about that later.

Jane Yes, we can talk about that later. This is the kind of information we'll be sharing with all of you on these telecons. I have it broken down hour by hour, exactly when all of the press conferences and briefings and NASA TV and Web stuff will be taking place.

Eric Is that on the Web site now or will it be?

Jane No, not yet. It's still kind of a moving target.

Anita Basically, the commentated live feed for mission ops is going to start about 7:00 p.m. Pacific Time that evening, the 30th. Basically, you'll see the Doppler on that night, but you won't see any pictures until the next morning. Right, Eric?

Eric Yes.

Jane There will be a lot of commentary and live interviews and so forth, starting in the morning on Wednesday the 30th and then, as it gets closer to the actual orbit insertion, there will be NASA TV pretty much from 6:00 p.m. on.

Eric Ellis may have mentioned this, but because of the insertion burn, the project decided not taking images until after the burn, so that means that we will have the images in the morning. There's going to be a press conference on the following day, and then we'll have some images.

Dr. Miner Yes, I knew that was the case. I didn't know exactly when the plan was to transmit them back because I've not been following the SOI and development. It will be interesting to see that, even from Yellowstone.

Jane It's going to be awesome to see it from Yellowstone.

Anita I was just looking, Casper, Wyoming is a Mars Museum Alliance member and I seem to remember, though, that she said they don't get NASA satellite up there, but hopefully you can it in Yellowstone.

Ellis, thank you so much.

Dr. Miner My pleasure.

Anita We really appreciate it. I didn't give you much time.

Dr. Miner You gave me 24 hours. That was enough.

Anita Anybody else before we sign off?

M Thank you very much for everything.

M The next one is Tuesday?

Anita Next Tuesday is back to Mars. We're alternating now, Mars and Saturn every week. This seems like a good way to keep our momentum going.

Jane The following week, we'll be back on Saturn.

Anita Right, every other week. I'll be sending out the Monday reminders and tell you which planet we're on.

Eric Sounds good. We just got synchronized in the Solar System.

Anita Thank you, Ellis

Dr. Miner Good-bye.

Anita Good-bye, everybody.